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Reciprocal Termination Charges**

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Abstract The aim of this paper is to study different regulatory effects on termination charges and social welfare. We employ a framework with a fixed network and two mobile networks competing in a market to study the following regulatory regimes: collusive and social welfare-maximising reciprocity, uniform termination charge, asymmetric regulation, and direct calling price. We incorporate the idea of partial consumer ignorance when calling to a mobile user and allow the network operator to discriminate between on-net and off-net calls by setting differential calling prices. Compared to the uniform termination charge and asymmetric regulation, it is shown in this paper that the regulator can improve social welfare, without too much intervention, by imposing reciprocity on termination charges. We also find that with stronger consumer ignorance the regulator is more capable of improving social welfare. Further we show that, depending upon the extent of consumer ignorance, direct regulation of calling prices may be a welfare-improving alternative over regulation of termination charges.

Keywords Telecommunications; Consumer ignorance; Termination Charges, Regulation

JEL classification L13; L50; L96

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1 Introduction

The markets for mobile telecommunications are typically oligopoly due to the barrier to entry. Although the introduction of mobile virtual network operators has increased competition, network operators are still considered monopolies because of the exclusive position on providing services in their own network. Therefore, regulation remains the main issue and interest in the telecommunications industry.

The interconnection behaviour and termination charges have played an important role in the recent research in telecommunications. Much research is based on the framework of Laffont, Rey, and Tirole[13][14] - henceforth LRTa and LRTb. They introduce two often adopted assumptions, balanced calling pattern and reciprocal termination charge, and suggest that a negotiated termination charge above marginal cost may be used as a collusive device to soften the competition.¹

Gans and King[11] introduce the idea of consumer ignorance. They argue that “consumers are often unable to identify which specific network they are calling to and are likely to base their calling decision on an average price rather than on actual prices.” They show that the *horizontal separation effect* follows the existence of consumer ignorance and pushes mobile termination charges and calling prices even higher than the monopoly level. Wright[20] confirms the excessive termination charges in Gans and King[11] and further suggests that a common (reciprocal) termination charge is a requirement to prevent mobile network operators from setting a termination charge above the monopoly level.

The introduction of number portability enables telephone users to retain their telephone numbers when changing to different networks. It makes networks even more indistinguishable and exacerbates consumer ignorance. Buehler and Haucap[3] argue that the welfare effects of

¹The reciprocal charge is when the two networks charge each other same termination fees. LRTa figures that regulators and antitrust authorities are likely to insist on the reciprocity of termination charges in the future. According to Ofcom[15] the mandatory reciprocity is one of the regulation options for the future termination regime on mobile network after 2001.

introducing mandatory mobile number portability is ambiguous and suggest that the mobile number portability is less likely to improve social welfare (i) the closer substitutes the mobile networks are, and (ii) the larger the market for fixed network telephony is.

Based on the framework of Gans and King[11], in section 2 we develop the basic model where one fixed network and two mobile networks compete in the market. Unlike other papers which usually ignore the mobile-to-mobile (MTM) or mobile-to-fixed (MTF) calls for simplicity, we consider a more complete case where subscribers call to *all* networks, including MTM, MTF and fixed-to-mobile (FTM) calls, to move closer to reality. In addition, we incorporate the idea of *partial consumer ignorance* (toward mobile networks) when calling to a mobile user and allow the network operator to set discriminatory calling prices for on-net and off-net calls.² To the best of our knowledge, this is the first paper taking the different extent of consumer ignorance when calling to different networks into account. Gans and King[11] assume that consumers are unable to distinguish the calls terminating in a mobile network from the calls terminating in the fixed network. This *complete consumer ignorance* results in a uniform pricing scheme in which the network operator will only set a uniform price for originating calls regardless of which network the calls are terminated since the outcome of discriminatory pricing is equivalent to the outcome of uniform pricing.³ By separating the consumer's ability on identifying the telephone numbers for mobile and for fixed networks, it not only reflects the current reality but also allows us to analyse the issues of discriminatory prices. We then study the different regulatory effects on termination charges and social welfare.

It is already known that the reciprocal termination charge can eliminate the problem of double-marginalisation (vertical separation) which happens when all the networks have monopoly power and usually pushes prices above the monopoly level. It also excludes the possibility of unstable or corner solution.⁴ For the above reasons, the implementation of reciprocity is considered to be a 'light-handed' regulatory regime to improve social welfare. Therefore, in

²Currently, in most countries, number portability is only available on transferring within mobile networks or within local fixed networks. The United States, Canada and Iceland are the only three countries that offer full number portability transferring between both fixed and mobile networks.

³Wright[20] and Buehler and Haucap[3] consider only FTM calls. Under their assumptions, the mobile subscribers do not call other mobile users and they also ignore MTF calls because their prices are set at marginal costs. Therefore there is no need to consider the complete consumer ignorance between mobile and fixed networks.

⁴For the proof see Economides, Lopomo and Woroch[9].

section 3, we study collusive reciprocal termination charge as a benchmark and find that the collusive reciprocal termination charge will result in a monopoly outcome. To achieve maximum welfare, the socially optimal termination charge should be set below-cost unless the market sizes of the networks are significantly asymmetric.

We then study different regulatory regimes in section 4. We start at the uniform termination charge to investigate the effect of vertical and horizontal separation and then examine the often adopted asymmetric regulation on the fixed network. Both regimes are found to be inferior to the collusive reciprocal regime. We also study the direct calling price regulation and suggest that it favors the small network and increases consumer surplus. It may be a better regime compared to the collusive reciprocity in terms of social welfare. In section 5, we extend our discussion to complete consumer ignorance and show that the regulatory outcome may be reversed if the extent of consumer ignorance is very strong. We conclude in section 6.

2 The Model and Assumptions

We consider a telecommunications industry with two independent mobile networks and a fixed network. To simplify the strategic interaction between network operators and focus on the decisive factor of termination charges, we assume that the market sizes of the networks are exogenous. The assumption of exogenous market share can be applied to a mature market where the market shares are almost fixed or to the case when the switching cost is high.⁵

We assume that the total number of consumers is fixed and each consumer subscribes to a network. We segment the telecommunications subscription market into fixed and mobile network sectors, and the market sizes are assumed fixed. The market sizes of mobile network 1, mobile network 2, and the fixed network are denoted by n , $1 - n$, and s respectively. The two

⁵The assumption of exogenous markets shares is also employed by Gans and King[11], Armstrong[2], Dewenter and Haucap[8] since it has proven extremely difficult to analyse termination rates with endogenous market shares, as the optimization problem is no longer supermodular (Buehler[4]).

One justification of exogenous market share is that switching to a different network involves some costs. For example, the subscriber need to inform others the change of his number, and it takes time to compare prices for different networks and familiar to the functional services of the new network. Therefore consumers may not switch to other networks over the relevant range of tariffs.

The case of exogenous market share can also be considered when the networks are not strong substitutes, for example if different networks cover different regions or consumer groups.

mobile networks share a market with the consumer base normalised to 1, and the parameter s can be interpreted as the relative market size of the fixed sector to the mobile sector.

We assume that the networks have the same cost and their marginal costs for originating and terminating a call are both c . Therefore the *actual* total marginal cost to complete a call is $2c$. However, when launching an off-net call, the termination network j will charge the origination network i a price denoted by t_{ij} , where $i, j = 1, 2, F$ and $i \neq j$ are associated with mobile network 1, 2 and the fixed network. This termination charge may differ from the marginal cost for terminating a call. Consequently, the *perceived* marginal cost that the network operator i faces to complete an off-net call is $c + t_{ij}$.

We assume that the consumers are charged linear prices and denote p_{i1} , p_{i2} and p_{iF} as the discriminatory prices for calling to network 1, 2 and the fixed network respectively from network i .⁶ While consumers cannot identify which mobile network they are calling to, they usually are able to distinguish the numbers for the fixed network from those for mobile networks. Therefore we assume that consumer ignorance exists only when the calls are made to a mobile network. We refer this case as *partial consumer ignorance* to differentiate from *complete consumer ignorance* in which the consumers cannot even recognise the difference between the fixed and mobile numbers. Because of partial consumer ignorance, the consumers only consider the average price when making calls to a mobile network. The expected price for consumers in network i to call a person in a mobile network is the weighted average of the calling prices to mobile networks, with weights given by the market shares of mobile networks. That is $p_{iM} = np_{i1} + (1 - n)p_{i2}$, $i = 1, 2, F$. Therefore, even though the network operators could set a differential price for calling to different mobile networks, the results are equivalent to the case when the networks are unable to discriminate different mobile networks. For this reason, we assume that the network operators set a uniform price for calls to mobile networks, *i.e.* $p_{i1} = p_{i2} = p_{iM}$, but a discriminatory price p_{iF} for calls to the fixed network. The framework is as shown in Figure 1.

⁶According to Carter and Wright[6], “one justification for using linear prices is that they appear common practice. In New Zealand, Clear and Telecom ultimately agreed a linear price...” Although two-part tariffs and other pricing schemes are very common, most prepaid phone card or pay-as-you-go schemes nowadays are still charged linear prices.

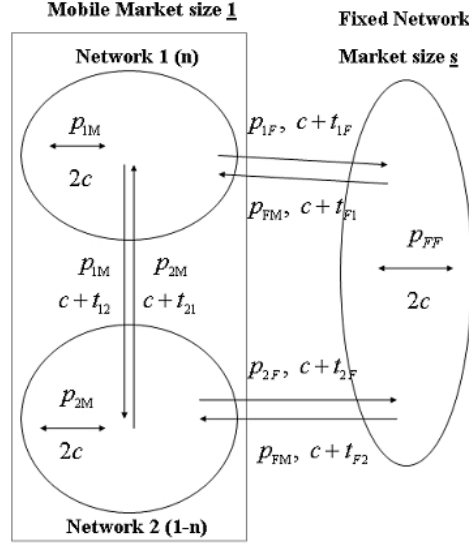


Figure 1: The framework

We assume that consumers are homogenous in their calling pattern. Given the price p_{ij} , a representative consumer in network i has demand of q_{ij} call minutes to call a person in network j , and derives utility $u(q_{ij})$ from the calls to a given person. Following Gabrielsen and Vagstad[12] and De Bijl and Peitz[7], we assume that the utility takes the form

$$u(q_{ij}) = \frac{1}{b}(aq_{ij} - \frac{1}{2}q_{ij}^2),$$

where $a, b > 0$, which gives a linear demand function for call minutes

$$q_{ij} = a - bp_{ij}.$$

The linear demand assumption is often adopted in the literature since it allows us to explicitly calculate the equilibrium values, for example prices and termination charges here, and to compare the equilibrium values over different regimes.

Furthermore, following LRTa and LRTb, we employ *balanced calling patterns* with which a consumer has an equal chance of calling a given consumer belonging to her network and another belonging to the rival networks. Therefore, the percentage of on-net calls of a network will equal the market share of that network. The profit of each network is composed of

origination profit and termination profit, and are given as

$$\begin{aligned}\pi_1 = & \underbrace{n[(p_{1M} - 2c)nq_{1M} + (p_{1M} - c - t_{12})(1 - n)q_{1M} + (p_{1F} - c - t_{1F})sq_{1F}]}_{\text{profit from originating calls}} \\ & + \underbrace{n[(t_{21} - c)(1 - n)q_{21} + (t_{F1} - c)sq_{F1}]}_{\text{profits from terminating calls}}.\end{aligned}\quad (1)$$

$$\begin{aligned}\pi_2 = & \underbrace{(1 - n)[(p_{2M} - c - t_{21})nq_{2M} + (p_{2M} - 2c)(1 - n)q_{2M} + (p_{2F} - c - t_{2F})sq_{2F}]}_{\text{profit from originating calls}} \\ & + \underbrace{(1 - n)[(t_{12} - c)nq_{12} + (t_{F2} - c)sq_{F2}]}_{\text{profits from terminating calls}}.\end{aligned}\quad (2)$$

$$\begin{aligned}\pi_F = & \underbrace{s[(p_{FM} - c - t_{F1})nq_{F1} + (p_{FM} - c - t_{F2})(1 - n)q_{F2} + (p_{FF} - 2c)sq_{FF}]}_{\text{profit from originating calls}} \\ & + \underbrace{s[(t_{1F} - c)nq_{1F} + (t_{2F} - c)(1 - n)q_{2F}]}_{\text{profits from terminating calls}}.\end{aligned}\quad (3)$$

Throughout the paper, we assume that the regulator values consumer surplus and industry profit equally so the welfare is measured by the sum of consumer surplus and network operators' profits, given by

$$W = CS + \pi_1 + \pi_2 + \pi_F, \quad (4)$$

where

$$CS = \frac{n}{2b}(q_{1M}^2 + sq_{1F}^2) + \frac{1 - n}{2b}(q_{2M}^2 + sq_{2F}^2) + \frac{s}{2b}(q_{FM}^2 + sq_{FF}^2), \quad (5)$$

denotes the consumer surplus and is derived from our assumption of linear demand function.

Due to the complexity and the difficulty of acquiring detailed information to set different socially optimal termination charges for different networks according to their respective circumstances, the welfare-maximising regulation is not usually practicable. Therefore, we use the collusive reciprocal termination charge as the benchmark case to investigate whether the regulator can improve the social welfare without a great deal of intervention.⁷ This is a two-stage game in which networks first negotiate reciprocal termination charges and then choose their retail prices simultaneously. We solve the game by backward induction.

⁷The assumption of reciprocal termination charge is often employed in the literature, for examples see LRTa, LRTb and Cambini and Valletti[5].

3 Benchmark: Collusive Reciprocal Termination Charge

Although the reciprocity can be mandated by the regulator, the networks still need to negotiate pairwise over termination charges without further regulation. In this section, we study collusive reciprocal termination outcomes as the non-regulatory benchmark case. The termination charges $t_{ij} = t_{ji}$ are decided between the associated pairs i and j through the process of negotiation. For convenience, we denote $t_m = t_{12} = t_{21}$, $t_1 = t_{1F} = t_{F1}$, and $t_2 = t_{2F} = t_{F2}$.

• Price competition

At the second stage, the network operators decide the calling prices p_{iM} and p_{iF} , $i = 1, 2, F$, simultaneously and non-cooperatively to maximise their own profits. Differentiating the profit equation (π_i) with respect to its price (p_{iM} and p_{iF}) and solving the first order conditions we obtain

$$p_{1M} = \frac{1}{2b} [a + 2bc + b(1 - n)(t_m - c)], \quad (6)$$

$$p_{1F} = \frac{1}{2b} [a + 2bc + b(t_1 - c)], \quad (7)$$

$$p_{2M} = \frac{1}{2b} [a + 2bc + bn(t_m - c)], \quad (8)$$

$$p_{2F} = \frac{1}{2b} [a + 2bc + b(t_2 - c)], \quad (9)$$

$$p_{FM} = \frac{1}{2b} \{a + 2bc + b[nt_1 + (1 - n)t_2 - c]\}, \quad (10)$$

$$p_{FF} = \frac{1}{2b} (a + 2bc) . \quad (11)$$

Note that termination charge has positive effect not only on the calling price for off-net calls but also for on-net calls when there is consumer ignorance. From equations (6), (8) and (11) we can see that the mobile networks' on-net prices are influenced by the MTM termination charge while the fixed network's on-net calling price is set to the monopoly level $\frac{1}{2b} (a + 2bc)$. The price for calling to a mobile network p_{iM} is positively (negatively) affected by the rival mobile network's market size if the termination charge is set above (below) the marginal cost.

When the rival network has larger market share, more calls will be terminated off-net. This results in a higher expected cost to complete a call and consequently a higher calling price if the termination charge is above the marginal cost. When the MTM termination charge equals the marginal cost ($t_m = c$), the mobile network operators will set $p_{1M} = p_{2M} = \frac{1}{2b} (a + 2bc)$, same as the monopoly level.

• The collusive termination charge

Taking into account the equilibrium prices derived at the stage 2, each two network operators negotiate their reciprocal termination charge without regulator's intervention at the first stage.⁸ The reciprocal MTM, fixed-to-mobile network 1 (termed FTM₁), fixed-to-mobile network 2 (termed FTM₂) termination charges are respectively decided by

$$\begin{aligned} t_m &= \arg \max_{t_m} \pi_1 + \pi_2, \\ t_1 &= \arg \max_{t_1} \pi_1 + \pi_F, \\ t_2 &= \arg \max_{t_2} \pi_2 + \pi_F. \end{aligned} \tag{12}$$

After substituting equations (6)–(11) into (1)–(3), we solve the first order conditions simultaneously and obtain the optimal collusive termination charges as follows,

$$t_m^* = t_1^* = t_2^* = c. \tag{13}$$

We obtain an outcome different from Gans and King[11]. They suggest that unregulated collusive termination charges will be set *above* the marginal costs due to the horizontal and vertical separation effects. In our model, the reciprocity removes both effects and the collusive termination charges are set *equal* to the marginal cost.⁹

Substituting (13) into equations (6)–(11) yields

⁸We suppose that profit transfer between networks is available and costless. For simplicity, we further assume that the network operators have equivalent power on negotiating a collusive termination charge.

⁹If the cost is asymmetric, the collusive termination charges will be equal to the associated network's average marginal costs weighted by their market sizes. That is, $t_1 = \frac{c_F + nc_1}{1+n}$, $t_2 = \frac{1}{1+(1-n)} (nc_2 - c_F - c_2)$, and $t_m = nc_1 + (1-n)c_2$ where c_i denotes the marginal cost of network i .

$$p_{iM}^* = p_{iF}^* = \frac{1}{2b}(a + 2bc). \quad (14)$$

The network operator will set a uniform monopoly price for originating a call regardless of which network the call terminates at. Because of the monopoly power over its own subscribers, each network enjoys the monopoly profit

$$\pi_i^* = \frac{1}{4b}(a - 2bc)^2(1 + s)\alpha_i, \quad (15)$$

where $\alpha_i = n, 1 - n$, s denotes the market share of each network i .

Substituting t_i^* and p_{ij}^* into (4) results in the collusive social welfare as follows,

$$W^* = \frac{3}{8b}(1 + s)^2(a - 2bc)^2. \quad (16)$$

Gans and King[11] consider only the FTM calls and do not consider the calls from mobile networks to the fixed network. The mobile network operator can thus unilaterally decide the FTM termination charge and have an incentive to set a high termination rate. In our two-way access model with negotiated reciprocal termination charge, a high termination charge not only increases the associated rival network's cost but also its *own* cost, which consequently increases the calling price and decreases the call volume. When the reciprocity is mandated, the network operators will internalise this effect and thus have incentives to lower the charge to the marginal cost. The double-marginalisation problem is eliminated because of the collusion.¹⁰

Although the negotiated reciprocal termination charge drags the collusive termination rate down to the marginal cost, the monopoly calling prices infer that, to increase the social welfare, the socially desirable prices should be set lower. The following subsection investigates how the regulator can influence the prices to improve welfare via the optimal choice of termination charge and the role of consumer ignorance in it.

¹⁰Instead of negotiating between network operators, if we make an extraordinary assumption that the regulator grants the mobile network operators the rights to decide the reciprocal termination charges, this collusive outcome will still come out. The mandatory reciprocity diminishes the decision maker's advantage.

This result also applies to the case with a dominant network which is capable of setting its termination charge before other network operators set theirs. The first-mover advantage of the dominant network is as well diminished by the reciprocity.

• Comparison between collusive and social welfare-maximising outcome

If the reciprocal termination charges were decided by a social welfare maximising regulator instead, she would solve the following problem,

$$\max_{t_m, t_1, t_2} W = CS + \pi_1 + \pi_2 + \pi_F.$$

From the first order conditions, the socially optimal reciprocal termination charges t_m^S , t_1^S and t_2^S are obtained as below,¹¹

$$t_m^S = \frac{1}{b} (2a - 5bc), \quad (17)$$

$$t_1^S = t_2^S = \frac{1}{b} (a - 3bc). \quad (18)$$

The comparison of termination charges gives the following observation.

Observation 1: (i) *The socially optimal termination charges are below the marginal cost (= collusive termination rate).*

(ii) *The socially optimal MTM termination charge is lower than the FTM (MTF) termination charge.*

Proof. Immediately proved by comparing equations between (17), (18) and the marginal cost as below,¹²

$$(i) \ t_m^S - c = -\frac{2}{b} (a - 2bc) < 0 \text{ and } t_i^S - c = -\frac{1}{b} (a - 2bc) < 0 \text{ where } i = 1, 2.$$

$$(ii) \ t_m^S - t_i^S = -\frac{1}{b} (a - 2bc) < 0. \blacksquare$$

To induce network operators to set a lower calling price, the regulator needs to set a termination charge below the marginal cost. This result supports the often suggested regime ‘bill-and-keep’ when the implementation of socially optimal regulation is not possible.¹³ The neg-

¹¹If the objective of the regulator is $W = \omega CS + (1 - \omega)(\pi_1 + \pi_2 + \pi_F)$, The interior maximisation results exist only when $\omega < \frac{2}{3}$.

¹²Throughout the paper we assume that $a > 2bc$ to ensure sufficient demand.

¹³Bill-and-keep is a zero reciprocal termination charge scheme and there is no monetary transfer between the networks: calls are made and bills are kept. The advantage of this approach is the savings from low transaction,

ative termination charges also infer lower calling prices under the welfare-maximising regime compare to the collusive one. Therefore, instead of comparing the prices with those under the collusive termination charge, we are more interested in whether an optimal termination charge can lead the calling price to the marginal cost level.

We then derive the equilibrium prices by substituting the socially optimal termination charges in (17) and (18) into (6)–(11) and obtain

$$p_{1M}^S = \frac{1}{2b} [a + 2bc - 2(1 - n)(a - 2bc)], \quad (19)$$

$$p_{2M}^S = \frac{1}{2b} [a + 2bc - 2n(a - 2bc)], \quad (20)$$

$$p_{FM}^S = p_{1F}^S = p_{2F}^S = 2c, \quad (21)$$

$$p_{FF}^S = \frac{1}{2b} (a + 2bc). \quad (22)$$

By setting a termination charge below marginal cost, the regulator induces network operators to set an off-net calling price equal to the true marginal costs $p_{ij}^S = 2c$, which is shown in equation (21). While the fixed network still charges a monopoly on-net price, the regulator can take advantage of partial consumer ignorance to influence the mobile networks' on-net price by choosing an optimal termination charge. From equation (19) and (20) we can see that since a small network originates more off-net calls and consequently faces a lower expected cost to complete a call with a below-cost termination charge, it charges a calling price below the actual cost $2c$. On the contrary, a large network charges a calling price above the actual cost. Although the calling prices between mobile networks deviate from the marginal cost when the sizes of mobile networks are asymmetric, the average calling prices to a mobile network will be equal to the actual marginal cost for completing a call.¹⁴ With consumer ignorance, the regulator can use termination charge as an instrument to achieve a more efficient outcome. However, the network operator loses its profit in originating on-net calls with consumer ignorance and therefore will prefer to make its numbers identifiable.

accounting and billing costs. However, we will prove that 'bill-and-keep' is considered to be a better regime only if there is no significant asymmetry in the network's market sizes in Section 5.

¹⁴This can be checked by $\frac{1}{2}(p_{1M}^S + p_{2M}^S) = 2c$.

Substituting price equations (19)–(22) into the profit equations (1)–(3) and the welfare function (4) we obtain

$$\pi_1^S = \frac{1}{4b} (a - 2bc)^2 (5 - 6n) (1 - 2n) n, \quad (23)$$

$$\pi_2^S = \frac{1}{4b} (a - 2bc)^2 (1 - 6n) (1 - 2n) (1 - n), \quad (24)$$

$$\pi_F^S = \frac{1}{4b} (a - 2bc)^2 s^2, \quad (25)$$

$$W^S = \frac{1}{8b} (a - 2bc)^2 \left[4n(1 - n) + 8s + 3s^2 + 3 \right]. \quad (26)$$

Although the aggregate profit in the mobile market is positive, the large mobile network may suffer loss because of the negative termination profit.¹⁵ Therefore the lump sum transfer may be needed to compensate the large network. The maximum social welfare is achieved when the mobile network operators have an equal market share. Substituting $n = \frac{1}{2}$ into equations (23) and (24) we can see that both mobile networks make no profit in the case of symmetric size.

4 Possible Regulatory Regimes

In this section, we study various regulatory approaches that could be introduced by the regulator and compare their effects to that of the collusive reciprocal termination charge. Beginning with the uniform termination charge and the asymmetric regulation on the fixed network, we then consider direct price regulation.

4.1 Uniform termination charge

Instead of mandatory reciprocity, the networks operator may be required to set a uniform (nondiscriminatory) termination charge for terminating calls, regardless of which network the calls originated from.¹⁶ We denote t_j^U as the uniform termination charge of the network j for

¹⁵ $\pi_1^S + \pi_2^S = \frac{1}{4}b^{-1} (1 - 2n)^2 (a - 2bc)^2 > 0$ if $n \neq \frac{1}{2}$. Furthermore, it is observed that small mobile network might benefit from the negative termination charge compare to the collusive regime.

¹⁶Uniform termination charge was once recommended by Oftel (The Office of Telecommunications). On Oftel[16] states that “Oftel believes consumers would benefit from a uniform rate for charges from fixed to

terminating the calls. That is, $t_j^U = t_{ij}$ where $i, j = 1, 2, F$ and $i \neq j$. The profit functions are therefore given as below,

$$\begin{aligned}\hat{\pi}_1^U &= n [(p_{1M} - 2c)nq_{1M} + (p_{1M} - c - t_2^U)(1 - n)q_{1M} + (p_{1F} - c - t_F^U)sq_{1F}] \\ &\quad + n [(t_1^U - c)(1 - n)q_{21} + (t_1^U - c)sq_{F1}],\end{aligned}\quad (27)$$

$$\begin{aligned}\hat{\pi}_2^U &= (1 - n) [(p_{2M} - c - t_1^U)nq_{2M} + (p_{2M} - 2c)(1 - n)q_{2M} + (p_{2F} - c - t_F^U)sq_{2F}] \\ &\quad + (1 - n) [(t_2^U - c)nq_{12} + (t_2^U - c)sq_{F2}],\end{aligned}\quad (28)$$

$$\begin{aligned}\hat{\pi}_F^U &= s [(p_{FM} - c - t_1^U)nq_{F1} + (p_{FM} - c - t_2^U)(1 - n)q_{F2} + (p_{FF} - 2c)sq_{FF}] \\ &\quad + s [(t_F^U - c)nq_{1F} + (t_F^U - c)(1 - n)q_{2F}].\end{aligned}\quad (29)$$

Differentiating the profit equations (27)–(29) with respect to prices (p_{iM} and p_{iF}) and simultaneously solving the first order conditions we obtain

$$\hat{p}_{1M}^U = \frac{1}{2b} [a + bc + bcn + bt_2^U(1 - n)], \quad (30)$$

$$\hat{p}_{2M}^U = \frac{1}{2b} [a + bc + bc(1 - n) + bnt_1^U], \quad (31)$$

$$\hat{p}_{FM}^U = \frac{1}{2b} [a + bc + bnt_1^U + bt_2^U(1 - n)], \quad (32)$$

$$\hat{p}_{1F}^U = \hat{p}_{2F}^U = \frac{1}{2b} (a + bc + bt_F^U), \quad (33)$$

$$\hat{p}_{FF}^U = \frac{1}{2b} (a + 2bc). \quad (34)$$

Substituting equations (30)–(34) into the profit equations (27)–(29), network operators then choose a termination charge simultaneously and noncooperatively to maximise their own profits. The equilibrium uniform termination charges are solved as follows,

mobile networks. This is particularly the case with number portability for mobile numbers available from 1 January 1999.” It also states that “Uniform retail prices (for an individual originating operator) for calls to all mobile networks would be appropriate. This would imply that uniform termination rates on all mobile networks would also be appropriate.”

$$t_1^U = \frac{(2n + 2s - 2n^2 + s^2 - ns)(a - 2bc) + ncb(4n + 4s - 4n^2 + 3s^2)}{(4n - 4n^2 + 4s + 3s^2)bn}, \quad (35)$$

$$t_2^U = \frac{(s - n + 1)(2n + s)(a - 2bc) + (1 - n)cb(4n + 4s - 4n^2 + 3s^2)}{(4n + 4s - 4n^2 + 3s^2)(1 - n)b}, \quad (36)$$

$$t_F^U = \frac{1}{2} \frac{a}{b}. \quad (37)$$

Observation 2 (Horizontal separation effect (Gans and King[11])): *The mobile network's termination charge is decreasing in its own market size while increasing in its rival mobile network's market size.*

Proof. See Appendix A.1 for the proof. ■

We can get the equilibrium calling prices p_{ij}^U , profits π_i^U and social welfare W^U by substituting t_j^U into (27)–(34) and welfare function (4). The outcomes are listed in Appendix A.1. We then compare the uniform termination outcomes with the collusive reciprocal outcomes and summarise the results in the following proposition.

Proposition 1 *Compared to the outcomes of the reciprocal termination charge, the uniform termination charge regime yields;*

- (i) *higher termination charge and higher calling prices except for the fixed on-net calls, which remains at the monopoly level as in the reciprocal termination regime;*
- (ii) *higher profit for small mobile network while lower profit for large mobile network and the fixed network;*
- (iii) *lower industry profit, consumer surplus and social welfare.*

Proof. See Appendix A.1 for the proof. ■

Without the implementation of reciprocity, both horizontal and vertical separation effects exist in the uniform termination charge regime. The off-net and MTM calling prices are therefore pushed beyond the monopoly level. A mobile network with sufficiently small market size can take advantage of consumer ignorance and make more profit from terminating calls,

whereas the fixed and the large mobile networks both make less profit. The excessive calling prices are detrimental for the aggregate industry profit and consumer's benefit, and therefore decrease social welfare.¹⁷

4.2 Asymmetric regulation on the fixed network

Because of its monopoly and dominant position, fixed networks have been subjected to various regulations around the world. We follow the most often adopted assumption that the termination charge for MTF calls is regulated at marginal cost while the FTM and MTM termination charges are left unregulated.¹⁸

Here we assume that the termination charge of the fixed network for terminating calls from mobile networks are regulated to its marginal cost c , that is $t_{1F} = t_{2F} = c$, while the mobile network operators cooperatively decide t_m . The unregulated mobile network operators retain the right to charge a termination price different from their costs and decide t_{F1} and t_{F2} unilaterally to maximise their profits.

At the second stage, the three network operators decide the calling prices \hat{p}_{ij}^R simultaneously to maximise their own profits. Solving the first order conditions, we obtain

$$\hat{p}_{1M}^R = \frac{1}{2b} [a + bc + bcn + bt_m(1 - n)], \quad (38)$$

$$\hat{p}_{2M}^R = \frac{1}{2b} [a + 2bc + bn(t_m - c)], \quad (39)$$

$$\hat{p}_{FM}^R = \frac{1}{2b} [a + bc + bnt_1 + bt_2(1 - n)], \quad (40)$$

$$\hat{p}_{1F}^R = \hat{p}_{2F}^U = \hat{p}_{FF}^U = \frac{1}{2b} (a + 2bc). \quad (41)$$

The FTM termination charges are now unilaterally decided by mobile network operators

¹⁷Complete consumer ignorance will enhance the horizontal effect and even more harmful from the social welfare's perspective.

¹⁸Ewers[10] states that "National Regulatory Authorities (NRAs) from various EU members have obliged incumbent fixed network operators to provide call termination on their network at cost-oriented rates and in a non-discriminatory manner, while mobile network operators are not forced to apply cost-oriented rates for terminating calls on their networks." Also see Peitz[17][18] for theoretical analysis to justify the intention to encourage the expansion of mobile penetration when the mobile industry is newly introduced.

while the MTM termination charge is negotiated by the two mobile network operators at the first stage. The termination charges are obtained as below,

$$\begin{aligned} t_m^R &= \arg \max \pi_1 + \pi_2 \\ &= c, \end{aligned} \tag{42}$$

$$\begin{aligned} t_{F1}^R &= \arg \max \pi_1 \\ &= \frac{1}{3nb} (a - 2bc + 3bcn), \end{aligned} \tag{43}$$

$$\begin{aligned} t_{F2}^R &= \arg \max \pi_2 \\ &= \frac{1}{3(1-n)b} (a + bc - 3bcn). \end{aligned} \tag{44}$$

and we summarise the results in the following proposition.

Proposition 2 (i) *With asymmetric regulation on the fixed network, the FTM termination charges are set above the marginal cost. Consequently, the fixed network charges a price higher than the monopoly level while the unregulated mobile networks set calling prices at the monopoly level.*

(ii) *While mobile networks benefit from the asymmetric regulation, the aggregate industry profit is lower than that without the regulation. Social welfare deteriorates when only the fixed network is regulated.*

Proof. See the proof in Appendix A.2. ■

The mobile network operators not only enjoy the monopoly power toward their own networks but also the decision power over the fixed network operator. While the MTM termination charge remains equal to the marginal cost, the unregulated mobile networks not only set the monopoly calling prices but also take advantage of asymmetric regulation to increase their termination profits by setting higher FTM termination charges. The standard double-marginalisation effect and the horizontal effect appear due to the lack of power of the regulated network on negotiation. This results in higher FTM termination charges and excessive FTM calling prices. Not only that consumers are worse off, the aggregate industry profit also

decreases since the loss in the fixed market surpasses the gain in the mobile market. Social welfare is consequently decreased.

4.3 Direct calling price regulation

Until now our discussion has focused on the regulation of termination charges. In this section we will investigate the effect of regulating the *prices* in the retail market to examine whether it would be an ideal alternative to the regulation on termination charges.

Assume that the regulator directly sets the calling prices at the expected perceived marginal costs and leaves the termination charges unregulated. The regulatory calling price for an on-net call is therefore $p_{ii} = 2c$ while the price for an off-net call is $p_{ij} = c + t_j$. Recall that the expected price for calling to a mobile network is $p_{iM} = np_{i1} + (1 - n)p_{i2}$. Imposing reciprocity, the regulatory calling prices are given as follows,

$$\hat{p}_{1M}^D = n(2c) + (1 - n)(c + t_m), \quad (45)$$

$$\hat{p}_{1F}^D = c + t_1, \quad (46)$$

$$\hat{p}_{2M}^D = n(c + t_m) + (1 - n)(2c), \quad (47)$$

$$\hat{p}_{2F}^D = c + t_2, \quad (48)$$

$$\hat{p}_{FM}^D = n(c + t_1) + (1 - n)(c + t_2), \quad (49)$$

$$p_{FF}^D = 2c. \quad (50)$$

Note that from (50) the price for fixed on-net calls is equal to the true marginal cost. The network operators negotiate pairwise a collusive termination charge to maximise their joint profits. The collusive termination charges with regulatory marginal calling price are then solved as follows,

$$t_m^D = \frac{1}{b} (a - bc), \quad (51)$$

$$t_1^D = \frac{1}{[8 + 3(1 - n)]b} [4a + (2a - 4bc + 3bcn)(1 - n)], \quad (52)$$

$$t_2^D = \frac{1}{[8 + 3(1 - n)]b} [4a + (2a - 4bc)n + 3bcn(1 - n)]. \quad (53)$$

If the calling prices are regulated at perceived marginal cost, network operators have incentives to negotiate a higher termination charge compared to the true termination cost c to increase the perceived cost and consequently increase the calling price. Substituting (51)–(53) into (45)–(50) and (1)–(4), the equilibrium prices, profits and social welfare are solved. We derive the outcomes in Appendix A.3.

We then compare the equilibrium outcomes with the unregulated collusive ones and summarise the results in the following proposition.

Proposition 3 *Compared to the collusive reciprocal termination charge, direct regulation of calling prices yields;*

- (i) lower calling price for FTF calls while higher price for FTM and MTF calls;*
- (ii) higher MTM calling prices for small mobile network and lower prices for the large network;*
- (iii) higher profit for the small mobile network but lower profit for the large and the fixed network;*
- (iv) lower industry profit, higher consumer surplus and social welfare when the market share is asymmetric.*

Proof. See the proof in Appendix A.3. ■

The distortion of the termination charge results in an excessive off-net calling prices while the on-net price is successfully lowered to the true cost. Because more (less) calls are terminated off-net, a small (large) mobile network is expecting a higher (lower) perceived cost when originating a call to a mobile user. This implies a MTM calling price above (below) the monopoly level for the small (large) network. The average MTM calling price is lower since it has more weight on the large network's price.

With lower average MTM calling price, consumers make more calls to a given mobile user. The small mobile network can therefore benefit from the increases in both price and calling volume for MTM calls, whereas the large network makes less profit due to a lower price. In terms of the profit from originating MTF calls, both mobile networks are worse off because of the excessive calling price and the decreased demand. The regulatory calling pricing harms

the fixed network since the regulation not only lowers demand for its off-net calls but also prohibits it from charging a monopoly price for on-net calls.

Although the introduction of the regulatory calling price will not be welcomed from the industry's perspective due to the decreased industry profit, it may benefit the consumers because of the cheaper MTM average calling price and a cheaper FTF price. The effect is reinforced with the asymmetric market size of mobile networks, and with the size of the fixed network. This advantage will outweigh the disadvantages associated with less MTF and FTM calls and the decreased industry profit. In aggregate, direct calling price regulation is superior to collusive reciprocal termination charge from the social welfare perspective in this case.

5 Complete Consumer Ignorance

In this section we examine how the extent of consumer ignorance influences the regulatory results with two examples: the welfare-maximising termination charges and direct price regulation.¹⁹ The availability of number portability between mobile and fixed networks in the United States and Canada can be a justification for us to extend consumer ignorance from the mobile networks only to the whole telecommunications market. We refer the latter case as complete consumer ignorance to distinguish it from (partial) consumer ignorance we employ in the previous sections.

While all the other notations and assumptions remain the same, with complete consumer ignorance, the expected price for consumers in network i here is $p_i = \alpha_1 p_{i1} + \alpha_2 p_{i2} + \alpha_F p_{iF}$ where p_i is the uniform (or expected average) calling price charged by network i , and $\alpha_1 = \frac{n}{1+s}$, $\alpha_2 = \frac{1-n}{1+s}$ and $\alpha_F = \frac{s}{1+s}$ are each network operator's market share relative to the whole

¹⁹The extent of consumer ignorance doesn't influence the monopoly-like outcomes with collusive reciprocal termination. Complete consumer ignorance enhances the horizontal effect which appears in both regimes of uniform termination charge and asymmetric regulation and therefore makes these two regulatory regimes even more inferior to the collusive reciprocal termination regime from the social welfare perspective.

subscription market 1 + s . The profit functions can then be rearranged as follows,

$$\begin{aligned}\pi_1 = & nq_1 [(p_1 - 2c)\alpha_1 + (p_1 - c - t_m)\alpha_2 + (p_1 - c - t_1)\alpha_F] \\ & + \alpha_1 [(t_m - c)(1 - n)q_2 + (t_1 - c)sq_F],\end{aligned}\quad (54)$$

$$\begin{aligned}\pi_2 = & (1 - n)q_2 [(p_2 - c - t_m)\alpha_1 + (p_2 - 2c)\alpha_2 + (p_2 - c - t_2)\alpha_F] \\ & + \alpha_2 [(t_m - c)nq_1 + (t_2 - c)sq_F],\end{aligned}\quad (55)$$

$$\begin{aligned}\pi_F = & sq_F [(p_F - c - t_1)\alpha_1 + (p_F - c - t_2)\alpha_2 + (p_F - 2c)\alpha_F] \\ & + \alpha_F [(t_1 - c)nq_1 + (t_2 - c)(1 - n)q_2].\end{aligned}\quad (56)$$

• Welfare-maximising outcome

Repeating all the steps as in section 3 we can get the following welfare-maximising termination charge with complete consumer ignorance,

$$\tilde{t}_m^S = \frac{(a - 2bc)(s^2 - 1) + 2bcn(1 - n)}{2n(1 - n)b}, \quad (57)$$

$$\tilde{t}_1^S = \frac{(a - 2bc)(1 + s)(1 - 2n - s) + 2bcns}{2nsb}, \quad (58)$$

$$\tilde{t}_2^S = \frac{(a - 2bc)(s + 1)(2n - s - 1) + 2bc(1 - n)s}{2n(1 - n)b}. \quad (59)$$

Comparing the above equations with the marginal cost yields the following results,

$$\tilde{t}_m^S - c = -\frac{(a - 2bc)(1 + s)(1 - s)}{2n(1 - n)b}, \quad (60)$$

$$\tilde{t}_1^S - c = -\frac{(a - 2bc)(1 + s)[n + s - (1 - n)]}{2nsb}, \quad (61)$$

$$\tilde{t}_2^S - c = -\frac{(a - 2bc)(1 + s)[(1 - n) + s - n]}{2n(1 - n)b}. \quad (62)$$

Recall that we have observed overall below-cost welfare-maximising termination charges and therefore suggest that bill-and-keep is a welfare-improving policy compared to the cost-

based regulation in the case of partial consumer ignorance. With complete consumer ignorance here, however, imposing the bill-and-keep regulation on all the networks may not be a good policy when there is significant asymmetry in networks' market size.²⁰ Take equation (60) for example, we can see that if the aggregate market size of the mobile networks is smaller (larger) than that of the fixed network, the regulated termination charges \tilde{t}_m^S should be set higher (lower) than the actual marginal cost.

Substituting equations (57)–(59) into the second stage equilibrium derived from the profit-maximising problems we obtain $\tilde{p}_i^S = 2c$ and consequently $\tilde{\pi}_i^S = 0$, where $i = 1, 2, F$. We then substitute \tilde{t}_i^S , \tilde{p}_i^S and $\tilde{\pi}_i^S$ into welfare equation (4) and obtain

$$\tilde{W}^S = \frac{1}{2b}(a - 2bc)^2(1 + s).$$

We can examine the effect of the extent of consumer ignorance by comparing the social welfare under complete consumer ignorance \tilde{W}^S with that under partial consumer ignorance W^S and report the findings in the following proposition.

Proposition 4 *With complete consumer ignorance, the efficient perfect competition outcome $\tilde{p}_i^S = 2c$ and $\tilde{\pi}_i^S = 0$ can be achieved by the socially optimal termination charges. The social welfare improves with complete consumer ignorance.*

Proof. $\tilde{W}^S - W^S = \frac{1}{8b}(a - 2bc)^2(4n + 4s - 4n^2 + 3s^2 - 1) > 0$. ■

While with partial consumer ignorance the regulator cannot influence the fixed on-net price, complete consumer ignorance gives the regulator greater ability to control all the networks' calling prices to achieve the first-best outcome. Even though the regulator weighs the consumer surplus and networks' profits equally, the profits are all transferred to the consumers and the networks make no profit.

²⁰For the same reason, we can infer that the bill-and-keep may be a better policy with discrimination pricing but may not be appropriate with uniform pricing when the market sizes of networks are asymmetric.

• Direct calling price regulation

When imposing direct calling price regulation, regulatory calling price for on-net calls is $p_{ii} = 2c$ while the price for off-net calls is $p_{ij} = c + t_i$. The regulatory calling prices are therefore given by

$$\begin{aligned} p_1^D &= \alpha_1(2c) + \alpha_2(c + t_m) + \alpha_F(c + t_1), \\ p_2^D &= \alpha_1(c + t_m) + \alpha_2(2c) + \alpha_F(c + t_2), \\ p_F^D &= \alpha_1(c + t_1) + \alpha_2(c + t_2) + \alpha_F(2c). \end{aligned}$$

Solving the decision problem in (12) we obtain the collusive termination charge with regulatory marginal calling price as follows,

$$\tilde{t}_i^D = \frac{1}{b} (a - bc), \quad i = 1, 2, F.$$

Substituting \tilde{t}_i^D into p_i^D gives the following equilibrium prices,

$$\begin{aligned} \tilde{p}_1^D &= \frac{1}{(1+s)b} (a - an + as + 2bcn), \\ \tilde{p}_2^D &= \frac{1}{(1+s)b} (an + as + 2bc - 2bcn), \\ \tilde{p}_F^D &= \frac{1}{(1+s)b} (a + 2bcs). \end{aligned}$$

We then substitute \tilde{t}_i^D and \tilde{p}_i^D into (54)–(56) and (4) and get the equilibrium profits and welfare as below,

$$\begin{aligned} \tilde{\pi}_1^D &= \frac{(a - 2bc)^2}{(1+s)^2 b} \left[(1-n)^2 + s^2 \right] n, \\ \tilde{\pi}_2^D &= \frac{(a - 2bc)^2}{(1+s)^2 b} \left(n^2 + s^2 \right) (1-n), \\ \tilde{\pi}_F^D &= \frac{(a - 2bc)^2}{(1+s)^2 b} \left[(1-n)^2 + n^2 \right] s, \\ \tilde{W}^D &= \frac{(a - 2bc)^2}{2(1+s)^2 b} \left(1 - n + n^2 + 2s + 2s^2 + s^3 + 4n^2 s - 4ns \right). \end{aligned}$$

We can see that the effect of the direct calling price regulation by comparing the above equilibrium outcomes with the unregulated collusive ones. The results are summarised in the following proposition.

Proposition 5 *(i) when a network's market share is smaller (larger) than its rivals' aggregate market share, it charges a price above (below) the monopoly level.*

(ii) The direct price regulation advantages the smaller network but harms the larger network. The distortion may be detrimental for both consumers and the industry, and consequently decrease the social welfare.

Proof. See the proof in Appendix B. ■

Note that the direct calling price regulation decreases social welfare with complete consumer ignorance while it improves social welfare with partial consumer ignorance.²¹ The reason for this contradictory outcome is as follows. When consumer ignorance does not exist, the prices for on-net calls are not influenced by the excessive termination charges and can be lowered to the level of true marginal costs. Although consumers suffer from the excessive off-net calls, they benefit from the low price for on-net calls. With complete consumer ignorance, both on-net and off-net calling prices are influenced by the excessive termination charge and this disadvantages consumer surplus.²²

6 Conclusion and Policy Implications

Although the telecommunications markets have been liberalised and competition has been fostered, the need of regulators' intervention is suggested across the world. Using a framework where a fixed network and two mobile networks compete in a market in the presence of consumer ignorance, we have studied different regulatory regimes: collusive and social welfare-maximising reciprocity, uniform termination charge, asymmetric regulation on the fixed network, and direct calling price regulation.

²¹Similarly, we can infer that the direct calling price may be a better policy with discrimination pricing scheme but not when uniform pricing is employed.

²²It can be checked that $(\tilde{p}_1^D + \tilde{p}_2^D + \tilde{p}_F^D) > (p_1^* + p_2^* + p_F^*)$, the average price increases with direct calling price regulation. This implies that the consumers are worse off under the regulatory calling prices regime.

We have found that with the existence of consumer ignorance, the termination charge not only affects off-net calls but also on-net calls since the consumer cannot distinguish on-net calls from off-net ones. Therefore the regulatory effect of termination charge will be reinforced. Depending on the different regulatory regimes, the influence of consumer ignorance can be either positive or negative. Given that the termination charge is regulated at the socially optimal level, the regulator can achieve a more efficient regulatory outcome with a greater extent of consumer ignorance, while it is detrimental for the dominant (larger) network. The result provides an explanation why the dominant network operators are usually against the implementation of number portability whereas the regulators across countries require mobile number portability.²³

It is clear from the EU and the UK experience that the approach and the extent of regulation have been kept under review as market conditions change. Uniform termination charge was once recommended by Oftel. It was proposed in the statement of Oftel[16] that “...consumers would benefit from a uniform rate for charges from fixed to mobile networks. This is particularly the case with number portability for mobile numbers available from 1 January 1999.” However our findings have suggested that this statement is fallacious. We have shown that both vertical and horizontal separation effects exist when a uniform termination charge is adopted, which lead to an excessive termination rate. Moreover, contrary to the advice of Oftel, we have found that the existence of consumer ignorance will enhance the horizontal separation effect and make the uniform termination regime even more inadequate from the social welfare’s perspective.

The asymmetric regulation which applies to incumbent or dominant network operators only is a common practice. In Europe, National Regulatory Authorities (NRAs) are required to impose regulations on those operators with significant market power. The incumbent fixed network operators are often obliged to provide termination at cost-based rates while mobile network operators are free from this obligation. We have demonstrated that the asymmetric regulation should be removed, soon as the sustainable competition is ensured, since it decreases both industry and consumer welfare.

²³One justification is that the number portability reduces switching cost and therefore increases the competition. See Buehler and Haucap[3] for detailed discussion.

In fact, Ofcom recently launched a debate about the future termination regime on mobile networks after 2011. According to Ofcom[15] the options include: (1) incremental costs only; (2) reciprocity between fixed and mobile; (3) bill-and-keep; (4) deregulate mobile termination; and (5) deregulate *all* termination. From our analysis we may recommend bill-and-keep on condition that the market shares of network operators are not too asymmetric. Otherwise the regulator can improve social welfare, without too much intervention, simply by imposing reciprocity on termination charges. Mandatory reciprocity between fixed and mobile will help to eliminate both vertical and horizontal separation effects and bring the termination rate to the level of marginal cost. It bears similar regulatory effect of incremental costs regulation while saves the costs for the regulator to monitor the network operators' cost structures.

Direct calling price regulation may be a welfare-improving alternative instead of regulating termination charges on condition that the consumers are not completely ignorant about the network they are calling to. Although it is detrimental to the industrial profits, it favours the small network and consumers.

Finally, we suggest that the extent of consumer ignorance has a crucial effect on the regulatory outcomes. The regulator is more capable of manipulating the termination charge to improve the social welfare when the extent of consumer ignorance is high. However, we have also demonstrated that greater extent of consumer ignorance may adversely affect the welfare-improving outcomes of direct calling price regulation. Therefore the regulator should be reminded to take the extent of consumer ignorance into consideration since the same regulation may have opposite results with different extent of consumer ignorance.

Appendix

Throughout the analysis in Appendix, we assume that the market size of the fixed network is not extremely different from the mobile market and therefore take the value $0.5 \leq s \leq 1.5$ for the fixed network's market size.

A Possible Regulatory Regimes: Proof

A.1 Uniform termination charge

• The proof for Observation 2.

We take t_1^U for example and partially differentiate it with respect to mobile network 1's market share which yields

$$\frac{\partial t_1^U}{\partial n} = \frac{(a - 2bc) A_1}{[4n(1 - n) + 4s + 3s^2]^2 n^2 b} < 0,$$

where

$$A_1 = (8n + 10s + 3s^2) (2n^2 - s^2) - 8(n + s) (n + s + n^3),$$

decides the sign of $\frac{\partial t_1^U}{\partial n}$. It is shown in Figure (A.1.1) that $A_1 < 0$ which implies that the uniform termination charge is decreasing in its own market share.

We then partially differentiate t_2^U with the mobile network 1's market share n and obtain

$$\frac{\partial t_2^U}{\partial n} = \frac{(a - 2bc) A_2}{[4n(1 - n) + 4s + 3s^2]^2 (1 - n)^2 b} > 0,$$

where

$$A_2 = 8n^2 (n - 1)^2 + 10s^2 (s + 1) + 3s^2 (s^2 - 2n^2) - 4s (2n^3 - n^2 - ns - 1),$$

decides the sign of $\frac{\partial t_2^U}{\partial n}$. Figure (A.1.2) shows that $A_2 > 0$ and the uniform termination charge is increasing in the rival mobile's market share.

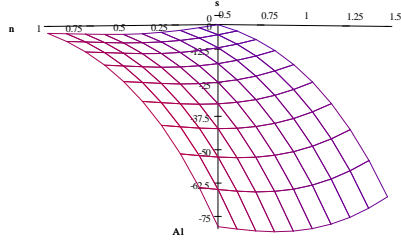


Figure A.1.1: A_1

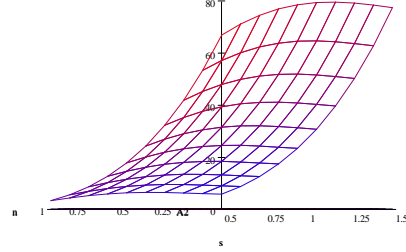


Figure A.1.2: A_2

• The equilibrium outcomes with the optimal uniform termination charge

$$p_{1M}^U = \frac{2(1-n)n(3a+2bc) + sn(a-2bc) + 4s^2(a+bc) + s(5a+6bc)}{2[4n(1-n) + 4s + 3s^2]b},$$

$$p_{2M}^U = \frac{2(n+s-n^2)(3a+2bc) - sn(a-2bc) + 4s^2(a+bc)}{2[4n(1-n) + 4s + 3s^2]b},$$

$$p_{FM}^U = \frac{8na(1-n) + 2scb(s+1) + sa(5s+7)}{2[4n(1-n) + 4s + 3s^2]b},$$

$$p_{1F}^U = p_{2F}^U = \frac{3a+2bc}{4b},$$

$$p_{FF}^U = \frac{a+2bc}{2b},$$

$$\begin{aligned} \pi_1^U &= \frac{(a-2bc)^2}{16b[4n(1-n) + 4s + 3s^2]^2} \\ &\times (64ns + 32n^2 - 80n^3 + 64n^4 - 16n^5 + 32s^2 + 64s^3 + 40s^4 + 8s^5 + 68ns^2 + 9ns^5 \\ &- 80n^2s + 16ns^3 + 16n^3s + 16ns^4 - 16n^4s + 16n^5s - 80n^2s^2 - 4n^3s^2 - 24n^3s^3), \end{aligned}$$

$$\begin{aligned} \pi_2^U &= \frac{(a-2bc)^2}{16b[4n(1-n) + 4s + 3s^2]^2} \\ &\times (32ns + 16n^2 - 16n^3 - 16n^4 + 16n^5 + 16s^2 + 56s^3 + 56s^4 + 17s^5 \\ &+ 104ns^2 + 32n^2s + 56ns^3 - 112n^3s - 16ns^4 + 64n^4s - 9ns^5 - 16n^5), \end{aligned}$$

$$\begin{aligned}
\pi_F^U &= \frac{1}{8} \left[4n(1-n) + 4s + 3s^2 \right]^{-2} b^{-1} (a - 2bc)^2 s \\
&\quad \times (32ns + 16n^2 - 32n^3 + 16n^4 + 18s^2 + 60s^3 + 59s^4 + 18s^5 \\
&\quad + 88ns^2 + 48ns^3 - 64n^3s + 32n^4s - 88n^2s^2 - 48n^2s^3), \\
W^U &= \frac{1}{32} \left[4n(1-n) + 4s + 3s^2 \right]^{-2} b^{-1} (a - 2bc)^2 \\
&\quad \times (224ns + 112n^2 - 224n^3 + 112n^4 + 112s^2 + 364s^3 + 544s^4 + 395s^5 \\
&\quad + 108s^6 + 572ns^2 - 16n^2s + 680ns^3 - 416n^3s + 288ns^4 + 208n^4s \\
&\quad - 380n^2s^2 - 680n^2s^3 - 384n^3s^2 - 288n^2s^4 + 192n^4s^2).
\end{aligned}$$

• The proof for Proposition 1

The comparisons of the uniform termination outcomes with collusive reciprocal termination outcomes are as follows,

$$\begin{aligned}
t_1^U - c &= \frac{(a - 2bc) [2(1 - n) + s] (n + s)}{[4n(1 - n) + 4s + 3s^2] nb} > 0, \\
t_2^U - c &= \frac{(a - 2bc) (1 - n + s) (2n + s)}{[4n(1 - n) + 4s + 3s^2] (1 - n) b} > 0, \\
t_F - c &= \frac{(a - 2bc)}{2b} > 0, \\
p_{1M}^U - p_{1M}^* &= \frac{(a - 2bc) (1 - n + s) (2n + s)}{2 [4n(1 - n) + 4s + 3s^2] b} > 0, \\
p_{1M}^U - p_{1M}^* &= \frac{(a - 2bc) (1 - n + s) (2n + s)}{2 [4n(1 - n) + 4s + 3s^2] b} > 0, \\
p_{2M}^U - p_{2M}^* &= \frac{(a - 2bc) [2(1 - n) + s] (n + s)}{2 [4n(1 - n) + 4s + 3s^2] b} > 0, \\
p_{FM}^U - p_{FM}^* &= \frac{(a - 2bc) [4n(1 - n) + 3s + 2s^2]}{2 [4n(1 - n) + 4s + 3s^2] b} > 0, \\
p_{1F}^U - p_{1F}^* &= p_{2F} - p_{2F}^* = \frac{a - 2bc}{4b} > 0, \\
p_{FF}^U - p_{FF}^* &= 0,
\end{aligned}$$

$$\pi_1^U - \pi_1^* = \frac{(a - 2bc)^2}{16b} A_3 \quad \begin{matrix} \geq \\ < \end{matrix} 0,$$

where

$$A_3 = \frac{(64ns + 32n^2 - 144n^3 + 192n^4 - 80n^5 + 32s^2 + 64s^3 + 40s^4 + 8s^5 + 4ns^2 - 208n^2s - 144ns^3 + 80n^3s - 116ns^4 + 112n^4s - 27ns^5 - 48n^5s - 304n^2s^2 - 96n^2s^3 + 220n^3s^2 + 72n^3s^3)}{[4n(1 - n) + 4s + 3s^2]^2} \quad \begin{matrix} \geq \\ < \end{matrix} 0,$$

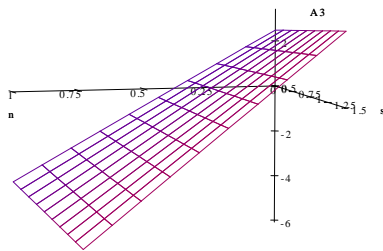
is depicted in Figure (A.1.3).

$$\pi_2^U - \pi_2^* = \frac{(a - 2bc)^2}{16b} A_4 \quad \begin{matrix} \geq \\ < \end{matrix} 0,$$

where

$$A_4 = \frac{(176n^3 - 48n^2 - 96ns - 208n^4 + 80n^5 - 48s^2 - 104s^3 - 76s^4 - 19s^5 - 56ns^2 + 224n^2s + 120ns^3 - 48n^3s + 116ns^4 - 128n^4s + 27ns^5 + 48n^5s + 356n^2s^2 + 120n^2s^3 - 220n^3s^2 - 72n^3s^3)}{[4n(1 - n) + 4s + 3s^2]^2} \quad \begin{matrix} \geq \\ < \end{matrix} 0,$$

is depicted in Figure (A.1.4).



A.1.3: A₃

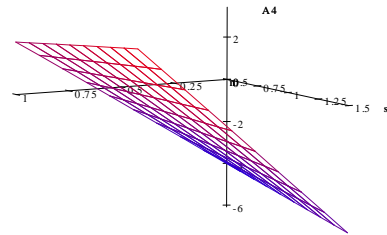


Figure A.1.4: A₄

Both Figure (A.1.3) and (A.1.4) show that the small network makes more profit compared to that of the reciprocal termination regime.

$$\pi_1^U + \pi_2^U - (\pi_1^* + \pi_2^*) = \frac{(a - 2bc)^2}{16b} A_5 < 0,$$

where

$$A_5 = -\frac{[16n^2(1-n)^2(1+s) + s^2(40s + 36s^2 + 11s^3 + 16) + 4(13s + 6s^2 + 8)(1-n)sn]}{[4n(1-n) + 4s + 3s^2]^2} < 0.$$

$$\pi_F^U - \pi_F^* = \frac{(a - 2bc)^2}{8b} A_6 < 0,$$

where

$$A_6 = -\frac{16n^2(1-n)^2 + s^2(20s + 7s^2 + 14) + 8sn(1-n)(3s + 4)}{[4n(1-n) + 4s + 3s^2]^2} < 0.$$

$$W^U - W^* = \frac{(a - 2bc)^2}{8b} A_7 < 0,$$

where

$$A_7 = -\frac{[16n^2(1-n)^2(11s + 5) + 4(121s + 70s^2 + 40)(1-n)sn + s^2(308s + 332s^2 + 109s^3 + 80)]}{[4n(1-n) + 4s + 3s^2]^2} < 0,$$

A.2 Asymmetric regulation on the fixed network

• The proof for Proposition 2

The comparisons of the asymmetric regulation outcomes with collusive reciprocal termination ones are as follows.

(i) $t_{F1}^R > c$ and $t_{F2}^R > c$ are followed from equations (43) and (44).

(ii) Substituting equations (42)-(44) into (38)-(41) and (1)-(4), the equilibrium outcomes are as follows,

$$\begin{aligned}
p_{1M}^R &= p_{2M}^R = p_{1F}^R = p_{2F}^R = p_{FF}^R = \frac{(a + 2bc)}{2b}, \\
p_{FM}^R &= \frac{(5a + 2bc)}{6b} > \frac{(a + 2bc)}{2b}, \\
\pi_1^R &= \frac{(a - 2bc)^2}{36b} [9n(1 + s) + 2s], \\
\pi_2^R &= \frac{(a - 2bc)^2}{36b} [9(1 - n)(1 + s) + 2s], \\
\pi_F^R &= \frac{(a - 2bc)^2}{36b} (1 + 9s)s, \\
W^R &= \frac{(a - 2bc)^2}{72b} (38s + 27s^2 + 27).
\end{aligned}$$

Consequently, $\pi_1^R > \pi_1^*$, $\pi_2^R > \pi_2^*$, $\pi_F^R < \pi_F^*$, $\pi_1^R + \pi_2^R + \pi_F^R < \pi_1^* + \pi_2^* + \pi_F^*$, and $W^R < W^*$ can be verified by comparing the above equilibrium with that in the case of collusive reciprocal termination charges.

A.3 Direct calling price regulation

• The equilibrium outcomes

Substitute (51)–(53) into (45)–(49), the equilibrium prices are obtained as follows,

$$p_{1M}^D = \frac{1}{b} (a - an + 2bcn), \quad (63)$$

$$p_{1F}^D = \frac{2}{[8 + 3(1 - n)]b} [2a + (a + 3bcn)(1 - n) + 2bc(1 + n)], \quad (64)$$

$$p_{2M}^D = \frac{1}{b} (an - 2bc + 2bcn), \quad (65)$$

$$p_{2F}^D = \frac{2}{[8 + 3(1 - n)]b} [2a + 4bc + (a - 2bc)n + 3bcn(1 - n)], \quad (66)$$

$$p_{FM}^D = \frac{2}{[8 + 3(1 - n)]b} [2a + 4bc + (2a - bc)n(1 - n)]. \quad (67)$$

By substituting equations (63)–(67) and (50) into (1)–(4) we solve the equilibrium profits π_i^D and welfare W^D as below,

$$\begin{aligned}\pi_1^D &= \frac{(a - 2bc)^2 n}{[8 + 3(1 - n)]^2 b} \\ &\quad \times \left(24s - 80n - 14ns - 71n^2 + 108n^3 + 6n^4 - 36n^5 + 9n^6 + 8n^2s - 2n^3s + 64 \right), \\ \pi_2^D &= \frac{(a - 2bc)^2 (1 - n)}{[8 + 3(1 - n)]^2 b} \\ &\quad \times \left(16s + 4ns + 64n^2 + 48n^3 - 39n^4 - 18n^5 + 9n^6 + 2n^2s + 2n^3s \right), \\ \pi_F &= \frac{(a - 2bc)^2 (1 - n) (2n + n^2 - 6n^3 + 3n^4 + 4) s}{[8 + 3(1 - n)]^2 b}, \\ W^D &= \frac{(a - 2bc)^2 (1 - n)}{2 [8 + 3(1 - n)]^2 b} \\ &\quad \times (96s - 16n + 28ns - 23n^2 + 69n^3 - 12n^4 - 27n^5 + 9n^6 + 64s^2 \\ &\quad + 48ns^2 - 26n^2s - 4n^3s + 2n^4s - 39n^2s^2 - 18n^3s^2 + 9n^4s^2 + 64).\end{aligned}$$

• The proof for Proposition 3

In Proposition 3, (i) and (ii) are proved by comparing equations (63)–(67) and (50) with $p_{ij}^* = \frac{1}{2b}(a + 2bc)$, which results in

$$\begin{aligned}p_{FF}^D - p_{FF}^* &= -\frac{(a - 2bc)}{2b} < 0, \\ p_{2F}^D - p_{2F}^* &= \frac{(a - 2bc) n(1 + 3n)}{2 [8 + 3n(1 - n)] b} > 0, \\ p_{FM}^D - p_{FM}^* &= \frac{5 (a - 2bc) n(1 - n)}{2 [8 + 3n(1 - n)] b} > 0, \\ p_{1F}^D - p_{1F}^* &= \frac{(a - 2bc) (1 - n) [1 + 3(1 - n)]}{2 [8 + 3n(1 - n)] b} > 0, \\ p_{1M}^D - p_{1M}^* &= \frac{(a - 2bc) (1 - 2n)}{2b} \begin{cases} \geq 0 \\ < 0 \end{cases} \text{ if } n \begin{cases} \leq \frac{1}{2} \\ > \frac{1}{2} \end{cases}, \\ p_{2M}^D - p_{2M}^* &= -\frac{(a - 2bc) (1 - 2n)}{2b} \begin{cases} \geq 0 \\ < 0 \end{cases} \text{ if } (1 - n) \begin{cases} \leq \frac{1}{2} \\ > \frac{1}{2} \end{cases}.\end{aligned}$$

For the proof of (iii) and (iv), we compare profits, consumer surplus and social welfare resulted from the direct calling price with those from the collusive reciprocal termination regime. The analysis and the results are as follows,

$$\pi_1^D - \pi_1^* = \frac{(a - 2bc)^2}{4b} D_1 \begin{matrix} \geq \\ < \end{matrix} 0,$$

where

$$D_1 = n \frac{(32s - 368n - 104ns - 245n^2 + 450n^3 + 15n^4 - 144n^5 + 36n^6 + 71n^2s + 10n^3s - 9n^4s + 192)}{[8 + 3(1 - n)]^2} \begin{matrix} \geq \\ < \end{matrix} 0,$$

is depicted in Figure (A.3.1).

$$\pi_2^D - \pi_2^* = \frac{(a - 2bc)^2}{4b} D_2 \begin{matrix} \geq \\ < \end{matrix} 0,$$

where

$$D_2 = (1 - n) \frac{(295n^2 - 32ns - 48n + 210n^3 - 165n^4 - 72n^5 + 36n^6 + 47n^2s + 26n^3s - 9n^4s - 64)}{[8 + 3(1 - n)]^2} \begin{matrix} \geq \\ < \end{matrix} 0,$$

is depicted in Figure (A.3.2). Both Figure (A.3.1) and (A.3.2) show that small network makes more profits under direct calling price regulation regime.

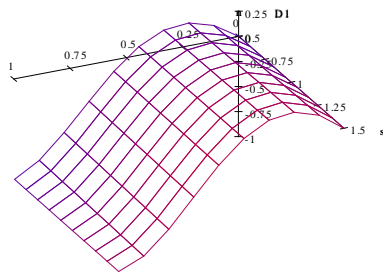


Figure A.3.1: D_1

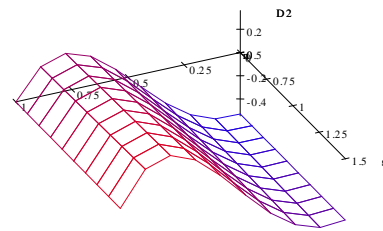


Figure A.3.2: D_2

$$\pi_F^D - \pi_F^* = \frac{(a - 2bc)^2}{4b} D_3 < 0,$$

where

$$D_3 = -s \frac{n(1-n)(39n^2 - 39n + 16) + s(3n^2 - 3n - 8)^2}{8 + 3(1-n)} < 0,$$

is depicted in Figure (A.3.3).

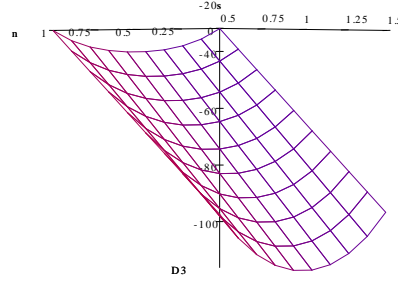


Figure A.3.3: D_3

$$W^D - W^* = \frac{(a - 2bc)^2}{8b} D_4 > 0,$$

where

$$D_4 = s \frac{(25n^2 - 176ns - 208n + 330n^3 - 75n^4 - 108n^5 + 36n^6 + 64s^2 + 48ns^2 + 130n^2s + 92n^3s - 46n^4s - 39n^2s^2 - 18n^3s^2 + 9n^4s^2 + 64)}{[8 + 3(1-n)]^2},$$

is depicted in Figure (A.3.4).

To analyse the regulation effect on social welfare, it is helpful to look into the regulation effect on consumer surplus CS and the aggregate industry profit $\Pi = (\pi_1 + \pi_2 + \pi_F)$. The consumer surplus with regulatory calling price CS^U and that with collusive termination charge CS^* can be obtained by substituting the equilibrium outcomes in the two regimes into equation (5). The difference $(CS^U - CS^*)$ is

$$CS^U - CS^* = \frac{(a - 2bc)^2}{8b} D_5 > 0,$$

where

$$D_5 = \frac{(75n^2 - 144ns - 624n + 990n^3 - 225n^4 - 324n^5 + 108n^6 + 192s^2 + 144ns^2 + 70n^2s + 148n^3s - 74n^4s - 117n^2s^2 - 54n^3s^2 + 27n^4s^2 + 192)}{[8 + 3(1 - n)]^2},$$

is depicted in Figure (A.3.5).

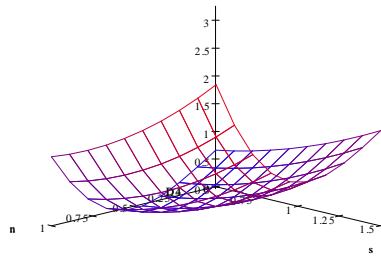


Figure A.3.4: D_4

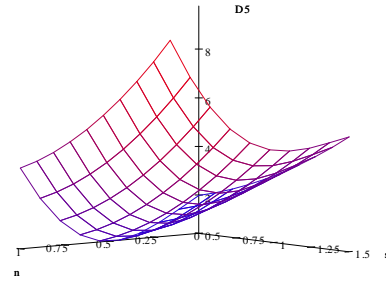


Figure A.3.5: D_5

Figure (A.3.4) and (A.3.5) show that the regulatory direct pricing benefits consumer and social welfare more when the sizes of mobile network are asymmetric. This can also be confirmed by $n = \arg \min(W^D - W^*) = \arg \min(CS^D - CS^*) = 0.5$.

We then compare the industry profit under direct calling price regulation Π^D with that under collusive termination charge Π^* and find that

$$\Pi^D - \Pi^* = \frac{(a - 2bc)^2}{4b} D_6 < 0,$$

where

$$D_6 = \frac{(16ns - 208n + 25n^2 + 330n^3 - 75n^4 - 108n^5 + 36n^6 + 64s^2 + 48ns^2 - 30n^2s + 28n^3s - 14n^4s - 39n^2s^2 - 18n^3s^2 + 9n^4s^2 + 64)}{[8 + 3(1 - n)]^2} < 0.$$

is depicted in Figure (A.3.6). It shows that the industry profit is worse off when the sizes of mobile network are asymmetric, which is also confirmed by $n = \arg \max(\Pi^D - \Pi^*) = 0.5$.

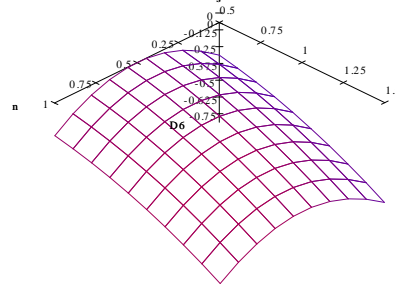


Figure A.3.6: D_6

From the comparisons above, we conclude that the direct regulation on the calling price is more welcomed by the consumers and the small network with the existence of partial consumer ignorance.

B Complete Consumer Ignorance

• The proof for Proposition 5

(i) Recall that the collusive prices $p_{iM}^* = p_{iF}^* = p^* = \frac{1}{2}b^{-1}(a + 2bc)$. Comparing equations \tilde{p}_i with p^* derives the following results.

$$\begin{aligned}\tilde{p}_1^D - p^* &= \frac{(a - 2bc)}{2b}(\alpha_2 + \alpha_F - \alpha_1), \\ \tilde{p}_2^D - p^* &= \frac{(a - 2bc)}{2b}(\alpha_1 + \alpha_F - \alpha_2), \\ \tilde{p}_F^D - p^* &= \frac{(a - 2bc)}{2b}(\alpha_1 + \alpha_2 - \alpha_F).\end{aligned}$$

The difference between regulatory and non-regulatory calling price mainly depends on the relative market share.

(ii) By comparing $\tilde{\pi}_i^D$ with $\pi_i^* = \frac{1}{4}b^{-1}(a + 2bc)\alpha_i(1 + s)$, and equation \tilde{W}^D with W^* in equation (16) we get the results listed below.

$$\pi_1^D - \pi_1^* = \frac{(a - 2bc)^2}{4b} \Delta_1,$$

where

$$\Delta_1 = \frac{(4n^2 - 2s - 8n + 3s^2 + 3)n}{(1 + s)^2},$$

is depicted in Figure (B.1).

$$\pi_2^D - \pi_2^* = \frac{(a - 2bc)^2}{4b} \Delta_2,$$

where

$$\Delta_2 = \frac{(4n^2 - 2s + 3s^2 - 1)(1 - n)}{(1 + s)^2},$$

is depicted in Figure (B.2).

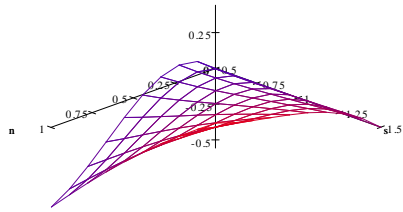


Figure B.1: Δ_1

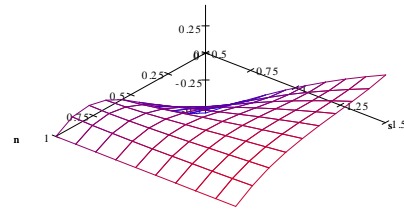


Figure B.2: Δ_2

$$\pi_F^D - \pi_F^* = \frac{(a - 2bc)^2}{4b} \Delta_F,$$

where

$$\Delta_F = \frac{(8n^2 - 2s - 8n - s^2 + 3)s}{(1 + s)^2},$$

is depicted in Figure (B.3).

$$W^D - W^* = \frac{(a - 2bc)^2}{8b} \Delta_W,$$

where

$$\Delta_W = \frac{(4n^2 - s - 16ns - 4n - s^2 + s^3 + 16n^2s + 1)}{(1 + s)^2},$$

is depicted in Figure (B.4).

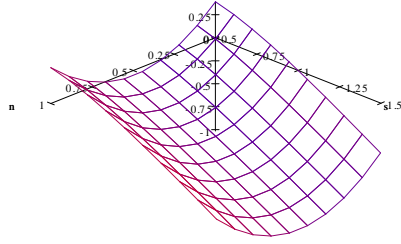


Figure B.3: Δ_F

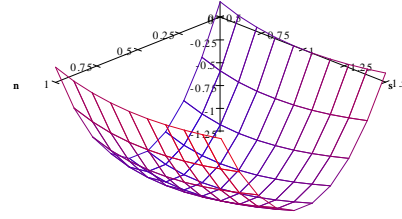


Figure B.4: Δ_W

The Figure (B.1), (B.2) and (B.3) all show that, with complete consumer ignorance, only the small firms can make more profit compared to the case with unregulated calling price. Because of the decrease in the aggregate industry profit and consumer surplus, the social welfare decrease and which is confirmed in Figure (B.4).

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